NITRIFICATION OF A SECONDARY MUNICIPAL EFFLUENT USING A ROTATING BIOLOGICAL CONTACTOR

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NITRIFICATION OF A SECONDARY MUNICIPAL EFFLUENT

USING A ROTATING BIOLOGICAL CONTACTOR

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CONCLUSIONS

The feasibility of utilizing the Rotating Biological Contactor (RBC) process for biological nitrification of a non-nitrified, secondary municipal effluent was evaluated. From results obtained through tests conducted under both summer and winter conditions in Ontario, it was established that the RBC process could produce a consistent, well-nitrified effluent.

It was concluded from testing conducted under summer conditions that:

(1) Nitrification efficiency decreased as the hydraulic loading on the RBC was increased from 0.8 IGPD/ft^2 to 3.2 IGPD/ft^2. A hydraulic loading of 3.2 IGPD/ft^2 produced an effluent of 0.77 mg/L average NH_3-N, with 71% of the effluent samples containing less than 1 mg/L NH_3-N.

(2) Nitrification efficiency increased as the disc rotational speed was increased from 1 rpm (7.85 fpm) to 2 rpm (15.7 fpm).

It was concluded from testing conducted under winter conditions that:

(1) At a constant hydraulic loading, nitrification efficiency decreased as the wastewater temperature decreased.

(2) A hydraulic loading rate of 2.4 IGPD/ft^2 produced an effluent of 1.05 mg/L average NH_3-N with 79% of the effluent samples containing less than 2 mg/L NH_3-N.

(3) Although the RBC process made a significant and quick recovery from one process upset, two successive upsets were detrimental to the process, in that total recovery of nitrification was limited and recovery time was lengthy.

RECOMMENDATIONS

The recommended hydraulic loadings, which follow, are for biological nitrification employing the RBC process, and are founded on results obtained from this study. Accordingly, these loadings can only be applicable when utilizing typical, secondary, municipal effluents (BOD_5 = 15 mg/L, SS = 15 mg/L, NH_3-N = 15 mg/L) and a disc rotational speed of 2 rpm (15.7 ft/min).

For summer operation, a hydraulic loading of 3.2 IGPD/ft^2 can be utilized to produce an effluent of 0.77 mg/L average NH_3-N, with 71% of the effluent samples containing less than 1 mg/L NH_3-N.

For winter operation, a hydraulic loading of 2.4 IGPD/ft^2 can be applied to produce an effluent of 1.05 mg/L average NH_3-N, with 79% of the effluent samples containing less than 2 mg/L NH_3-N.

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I. INTRODUCTION

I.I General

Protection of the aquatic environment may demand the control of Ammonia Nitrogen (NH_3-N) discharged in municipal wastewater treatment plant effluents. This release of Ammonia Nitrogen to receiving waters can adversely affect the quality of water in a number of ways. Ammonia Nitrogen poses a nitrogenous oxygen demand on the receiving waters, is toxic to fish, stimulates aquatic growth (eutrophication), and increases the chlorine dosage and contact time required for effective disinfection.

One method of controlling the release of Ammonia Nitrogen is by converting it to the form of Nitrate Nitrogen (NO_3-N) before discharge. This oxidation of NH_3-N to NO_3-N, which uses two groups of nitrifying bacteria, Nitrosomonas and Nitrobacter, is termed biological nitrification.

Of current interest is the use of the Rotating Biological Contactor (hereafter called RBC), an aerobic wastewater treatment process, as a means of biologically nitrifying municipal wastewaters.

In the RBC process, a population of microorganisms is grown and retained on the surface of a number of closely spaced discs. These discs, partially submerged in the wastewater, are mounted on a common shaft which is rotated, alternately exposing the microbial population to the atmosphere and to the wastewater. The fixed-film of biomass on the discs, in the presence of Oxygen (from air), continually oxidizes the Ammonia Nitrogen in the wastewater to Nitrate Nitrogen (nitrification). New cellular matter is synthesized from the energy liberated by the oxidation reaction. When the attached mass of microorganism on the discs reaches an excessive thickness, it is sloughed off the surface of the discs by the shearing force created by the rotation of the discs through the wastewater.

In this study, a package-type RBC unit, leased from Asdor Ltd.*, was employed to evaluate the efficiency of the RBC for the nitrification of a non-nitrified, secondary effluent. The study was conducted at the City of Guelph's Water Pollution Control Plant at Guelph, Ontario during the period March, 1977-March, 1978, and can be divided into two parts according to climatic conditions.

For the first part of the project (March, 1977-November, 1977, called summer conditions), the wastewater temperatures inside the RBC unit were above 13°C (55°F). It is generally acknowledged that biological activity may decrease below wastewater temperatures of 13°C or 55°F (20). During this period, the RBC was hydraulically loaded at four different rates (Table 1), and nitrification was observed for each loading. Each period was maintained long enough to ensure that steady-state conditions had been attained. Disc rotational speed for this study was set at 2 rpm (15.7 ft/min), thereby allowing a comparison of nitrification with an earlier study (1) in which disc rotational speed was set at 1 rpm (7.85 ft/min).

In the second part of the study (November, 1977-March, 1978), wastewater temperatures inside the RBC unit were below 13°C (called winter conditions). During this period, the RBC was hydraulically loaded in an attempt to establish a rate that would yield optimum (>90%) nitrification (Table 1).

Influent wastewater characteristics for the RBC varied slightly throughout the study, but were always representative of a non-nitrified secondary effluent (Table 2).

* The use of a trade name does not constitute a guarantee or warranty by the Ministry of the Environment and does not imply its approval to the exclusion of other products that may be suitable.

TABLE I

LOADING SCHEDULE (a)(b)

Loading Period	IGPD/ft^2 Hydraulic	# of Composite Samples	Temperature Range °C	DO Range (mg/L)
(a) Summer				
April 28/77-June 12/77	0.8	25	15-21°C	3-8
June 13/77-Aug. 9/77	1.6	18	18-24°C	2.4-4.4
Aug. 10/77-Oct. 23/77	3.2	24	15-20°C	2.0-4.2
Oct. 24/77-Nov. 25/77	2.4	12	10-16°C	2.5-6.5
(b) Winter				
Nov. 26/77-Jan. 23/78	2.4	21	1-10°C	3.7-9.0

(a) March 1/77-April 27/77 - startup period

(b) Jan. 24/78-March 13/78 - period of process upsets and recovery

TABLE 2

AVERAGE RBC INFLUENT WASTEWATER CHARACTERISTICS

FOR SUMMER AND WINTER OPERATION

	Summer Operation				Winter Operation
Hydraulic Load (IGPD/ft^2)	0.8	1.6	2.4	3.2	2.4
Parameter	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
NH_3-N	15.5	13.8	17.3	13.8	11.9
NO_3-N	1.9	0.1	0.3	0.6	3.6
TKN	18.1	15.4	21.0	15.8	14.6
NO_2-N	0.3	0.4	0.2	0.1	0.2
BOD	15.1	19.0	13.9	11.3	18.4
Filtered BOD	3.1	3.1	5.2	3.9	3.2
COD	54.4	45.7	45.9	49.0	52.2
Filtered COD	31.2	32.5	-	-	32.8
Organic Carbon	11.6	16.2	24.8	16.3	17.0
Inorganic Carbon	75.6	72.0	90.7	78.8	79.4
Suspended Solids	12.7	11.4	24.7	17.6	27.7
Dissolved Solids	-	867.4	865.6	898.5	876.4
Dissolved Phosphorus	0.3	0.7	0.4	0.3	0.3
Total Phosphorus	1.0	1.1	1.2	1.0	1.5
Alkalinity	334.1	317.3	335.4	329.3	317.4
pH*	7.6	7.6	7.9	7.7	7.7

* pH is not expressed in mg/l

1.2 Objectives

The objective of this project was to establish the feasibility of utilizing a Rotating Biological Contactor for biological nitrification when fed a non-nitrified, secondary municipal effluent under both summer and winter conditions encountered in Ontario.

Specific objectives for testing conducted under summer conditions were:

(1) to determine the effect of hydraulic loading on the nitrification capability of the RBC;

(2) to determine if nitrification could be increased with an increase in disc rotational speed.

Specific objectives for testing conducted under winter conditions were:

(1) at a constant hydraulic loading, to determine the effect on nitrification when wastewater temperatures fell below $13^{o}C$;

(2) to determine a winter hydraulic loading rate for the RBC process at which a minimum 90% nitrification level was maintained;

(3) to evaluate the response of the RBC system to a process upset.

2. LITERATURE REVIEW

2.1 Nitrogen Content in Domestic Sewage

Nitrogen in raw domestic wastewater occurs primarily in the form of Ammonia Nitrogen and Organic Nitrogen compounds (2). Although one investigation has estimated the Ammonia Nitrogen content of raw domestic wastewater to range as widely as 10 and 50 mg/L (3), another researcher (4), has established the average Ammonia Nitrogen content as varying closer to the range of 21.9 and 32.4 mg/L. A typical domestic secondary influent in Ontario may contain between 15 and 20 mg/L Ammonia Nitrogen (6).

2.2 Methods of Ammonia Nitrogen Removal

Several available methods of Ammonia Nitrogen removal have been explored; the three major processes economically feasible at present include (7): (a) biological nitrification (8,9); (b) air stripping of Ammonia Nitrogen by high pH (10, 11, 12); (c) removal of Ammonia Nitrogen by ion exchange (13, 14).

Other processes capable of removing both the oxidized and unoxidized forms of Nitrogen include, electrochemical methods for precipitation of Ammonia from raw wastewater (15), electrodialysis (16), reverse osmosis (17), distillation (17), breakpoint chlorination (12, 18) and algae harvesting (3).

Biological nitrification is probably the most common method of removing Ammonia Nitrogen from wastewater (7). Nitrification consists of oxidizing Ammonia to Nitrate using two groups of chemautotrophic bacteria, Nitrosomonas and Nitrobacter. These bacteria use Carbon Dioxide as their source of Carbon for cell material, and obtain energy for the process by

oxidizing inorganics in the wastewater. A simple description of the bacteria oxidation is:

$$2NH_4^+ + 3\,O_2 \xrightarrow[\text{action}]{\text{bacterial}} 2\,NO_2^- + 4H^+ + 2H_2O$$
(Nitrosomonas)

$$2NO_2^- + O_2 \xrightarrow[\text{action}]{\text{bacterial}} 2NO_3^-$$
(Nitrobacter)

2.3 Nitrification Using an RBC

Interest in employing an RBC as one way of nitrifying municipal wastewater developed primarily as a result of demands by regulatory agencies that, due to the adverse effects of nitrogenous materials discharged to receiving waters, treatment plant effluents should contain less nitrogen-based compounds (19). Further, biological nitrification is a very natural extension of any biological treatment system that can achieve high biodegradable carbonaceous organic removals.

It has been reported (20), that as the effluent BOD concentration from the RBC unit approaches 30 mg/L, nitrifying organisms begin to establish themselves in the RBC process. Further, when the effluent BOD concentration from the RBC unit reaches 8-10 mg/L, nitrification can be virtually completed ($<$ 1 mg/L NH_3-N in effluent of the RBC system).

Many factors affect the level of nitrification in an RBC process, among the more significant are hydraulic loading, wastewater temperature and disc rotational speed.

Hydraulic loading is presently the primary design criterion for nitrification and carbonaceous removal in an RBC due to its demonstrated first order removal kinetics. In pilot-scale testing conducted on a primary effluent (with BOD_5 = 150 mg/L), 90% nitrification was achieved at a hydraulic loading of 1.5 USGPD/ft^2. When the loading was decreased to 1.25 USGPD/ft^2, 95% nitrification was attained (20). From nitrification tests performed on a pilot-scale unit in Ontario (1), the Ontario Ministry of the Environment suggested design hydraulic loadings of 2.4 IGPD/ft^2 for summer conditions and 1.8 IGPD/ft^2 for winter conditions. These loadings were recommended for typical secondary effluents (BOD_5 = 15 mg/L, NH_3-N = 15 mg/L, SS = 20 mg/L).

Disc rotational speed can be utilized to alter nitrification efficiency. One study showed (20) that when disc rotation was increased from 2 rpm to 3.2 rpm and to 4.6 rpm superior nitrification occurred. Theory (21) indicates that higher disc rotation undoubtedly adds appreciable dissolved oxygen to the mixed liquor, and maintains the fixed-film of biological slime in a thin and active condition.

A similar characteristic of any biological treatment process is the effect of wastewater temperature on the rate of nitrification. The influent wastewater temperature affects the rate of activity of the microorganisms. It was found (21) that nitrification increases appreciably as wastewater temperature increases from 10°C to 20°C, but to a lesser extent between 20°C and 30°C. Further, it was reported (21) that for RBC processes under low hydraulic loadings, and achieving high degrees of nitrification, there was little loss in nitrification efficiency as temperature decreased

below 13°C. At high hydraulic loadings and low nitrification efficiencies, decrease in nitrification at temperatures below 13°C is more rapid.

2.4 MOE Research on the RBC Process

Past research in Ontario involving the RBC process has been conducted by pilot-scale investigations. The Ontario Ministry of the Environment has evaluated the RBC unit for carbonaceous removal of domestic wastewater through a year long study at Bolton, Ontario (22). The study concluded that under a continuous or intermittent feed basis when the organic loading is limited to about 1 lb BOD/day/1,000 ft^2 disc area, the RBC process is capable of producing a quality the same as that of secondary effluent.

At Strathroy, Ontario, a seven month study used lagoon effluent as feed to investigate the capability of Ammonia Nitrogen removal with a RBC. The study concluded that at loading rates of 8 IGPD/ft^2, Ammonia Nitrogen levels of lagoon effluents can be effectively reduced to less than 1 mg/L NH_3-N during the critical summer period (23).

At Guelph, Ontario, an eight month project studied nitrification of a non-nitrified, secondary quality effluent using an RBC. The study concluded that the RBC seemed capable of maintaining a stable process and producing a well-nitrified effluent under various temperature ranges (1).

3. METHODS AND MATERIALS

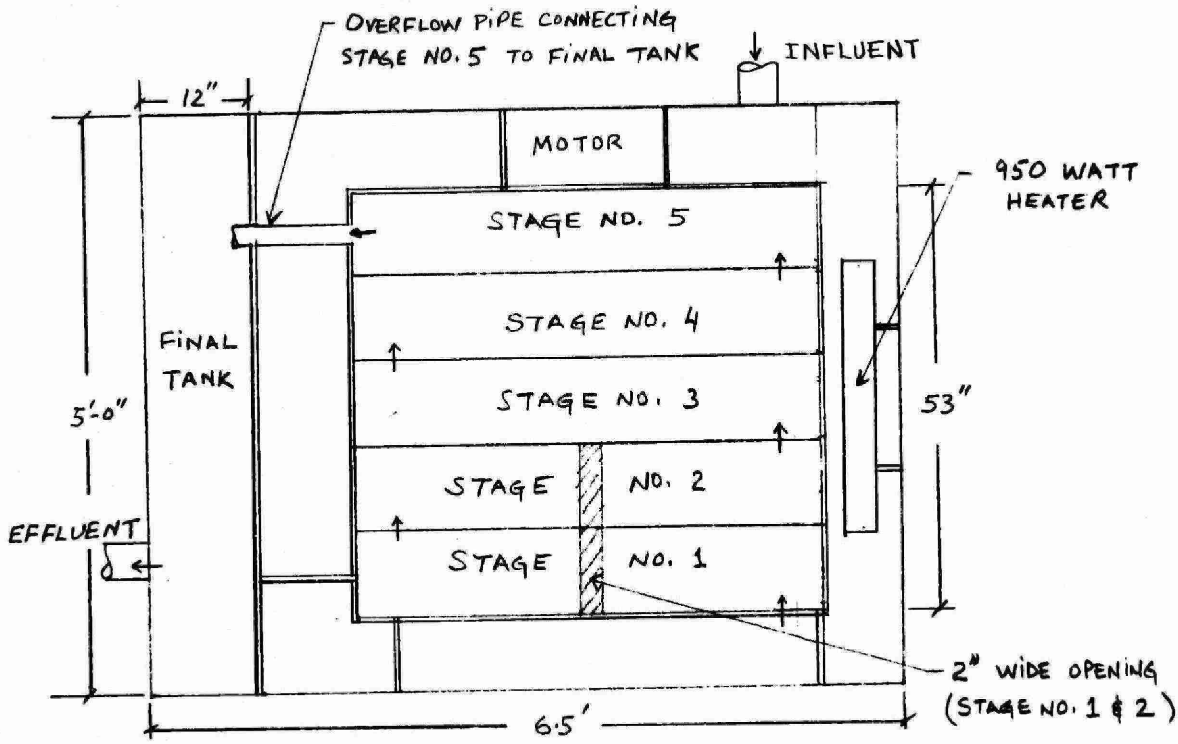
3.1 Description of Experimental Facilities

A small, package-type plant, marketed by Asdor Ltd., was utilized to evaluate the nitrification capabilities of the RBC Process. Since the design of these pilot-scale units varies according to equipment suppliers, a description of the particular RBC unit used in the Guelph study is in order.

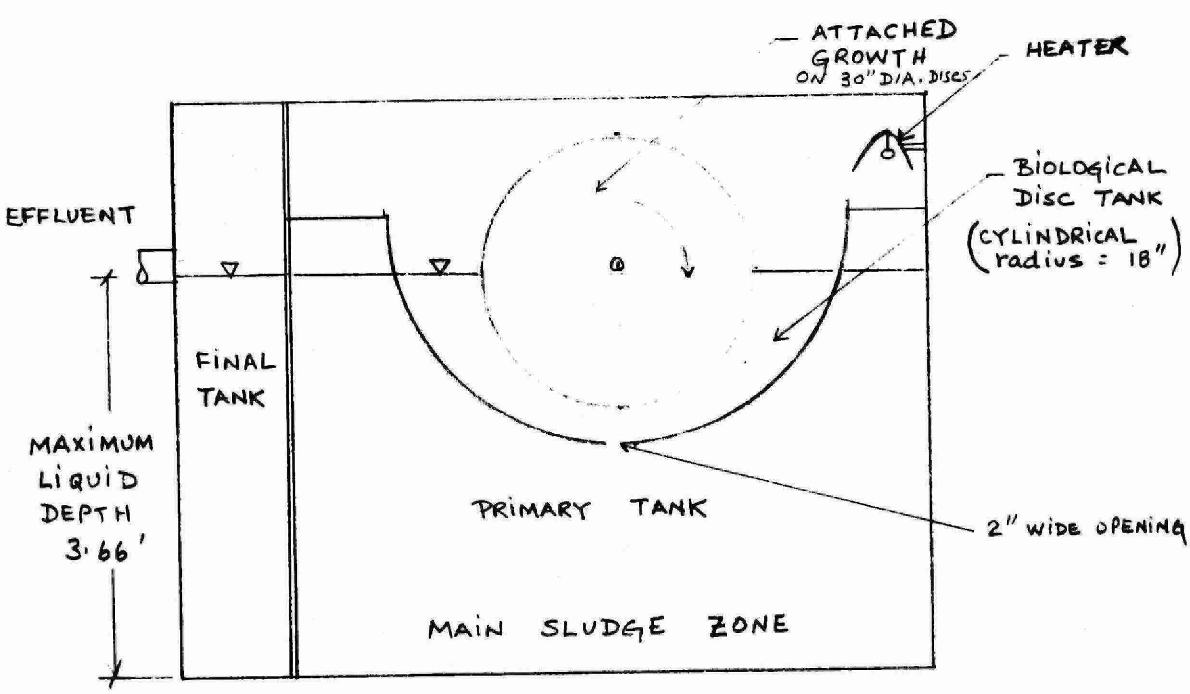
Figure 1 shows the RBC package plant in both plan and elevation, with the necessary details to clarify the operation of the process. The completely enclosed RBC unit was installed above-ground level, and the influent wastewater fed to the system by a variable speed pump.

Raw wastewater enters the system through an inlet in the primary tank (560 IG capacity). Particulate matter settles to the bottom of the primary tank under gravitational forces, creating a main sludge zone, while suspended and colloidal materials pass into the disc tank.

The disc tank (72 IG capacity) is a biological zone that is divided into five compartments or stages. The flow follows a serpentine path through the disc tank with the fifth stage overflowing into the final tank (115 IG capacity). The first two compartments of the disc tank are provided with two-inch wide openings at the bottom. When synthesis of cellular growth on the discs reaches an excessive thickness and "slough off", the biomass from the first two stages settles through these openings into the main sludge zone.



PLAN VIEW



ELEVATED VIEW

Fig. No. 1 RBC PILOT PLANT

The discs in the RBC unit are rotated by a 1/3 hp AC motor, and are connected to a gear reducer and a chain and sprocket speed reducer to provide the required rotational speed. A heating element, .95 Kilowatts, with a sixty-degree aluminum reflector is provided to generate enough heat to maintain the wastewater temperature in the RBC above freezing during winter conditions.

3.2 Sampling and Analytical Techniques

Composite samples (24 hours) of the RBC influent and effluent were collected on a regular basis using automatic samplers. Allylthiourea (ATU), was added as a preservative to the composite samples to inhibit nitrification in the sample bottle during the period of sample analysis. Initially, ATU was added at a concentration of 0.2 mg/L (April 1, 1977-November 21, 1977). As recommended by a MOE report (24), the ATU concentration was later increased to 1.0 mg/L (November 22, 1977-March 13, 1978).

Further testing which is being currently undertaken seems to indicate no significant difference between the different levels of the preservative on inhibition of nitrification.

Composite samples were analyzed for all Nitrogen forms (NH_3-N, NO_3-N, NO_2-N, TKN), Biochemical Oxygen Demand (BOD_5, Filtered BOD), Chemical Oxygen Demand (COD, Filtered COD), Phosphorus (Total and Dissolved), Solids (Suspended and Dissolved), Carbon (Organic and Inorganic), pH and Alkalinity. Procedures outlined in "Standard Methods" (5) were followed in these analyses.

Grab samples were collected of the RBC influent, effluent and all five stages of the biological zone. ATU was not added to the grab samples as the sample analyses were conducted with minimum delay. At the same time that grab samples were collected, dissolved oxygen of the influent, effluent and five stages of the RBC was measured. Temperature was measured often during the "summer" part of the study, but monitored on a continuous basis by an automatic temperature recorder during the "winter" part of the study.

3.3 Computer Reduction of Data

For the reduction of data obtained from the RBC study, a computer program was devised. The process data was stored in a matrix on a tape cassette. The program called for the data to be "read in" on a daily bais. Necessary calculations, such as percentage removal of Ammonia Nitrogen, were then calculated for the particular day. Other parameters obtained by manipulating the original data were also computed, e.g. Organic Nitrogen for the day was computed by subtracting NH_3-N from TKN. Finally, all daily computations were stored in memory.

In this manner, the computer read in values of the parameters from the starting to final day, making all the desired daily calculations and storing these values in memory. After the final day values were read in, the daily percentage reductions in memory were averaged.

Print out could occur on both a daily or total basis. That is, there could be a print out of all daily removal efficiencies, plus an average removal efficiency, computed over the duration of each hydraulic loading period.

4. PROCESS RESULTS AND DISCUSSION - SUMMER OPERATION

"Summer Conditions", defined earlier for wastewater temperatures above 13^{o}C, prevailed between April 29, 1977 - November 24, 1977. During this period, the RBC unit was loaded at four different hydraulic rates (0.8, 1.6, 2.4 and 3.2 IGPD/ft^2), and the biological nitrification capability of the RBC Process was evaluated (Summer Operation Summary - Table 3).

4.1 Effect of Hydraulic Loading on Nitrification

It was clearly established that Ammonia Nitrogen removal decreased as the hydraulic loading increased (Figure 2). Complete nitrification (over 99%) was achieved at hydraulic loadings of 0.8 IGPD/ft^2 and 1.6 IGPD/ft^2, but Ammonia Nitrogen removal decreased to 98.5% and 94.6% as the hydraulic loading was increased to 2.4 IGPD/ft^2 and 3.2 IGPD/ft^2 respectively. Similar to Ammonia Nitrogen removal, TKN removal rates also decreased as the hydraulic loading increased (Figure 2). TKN removal rates were in excess of 90% at hydraulic loadings of 0.8 IGPD/ft^2 and 1.6 IGPD/ft^2, but decreased to 86.2% at 2.4 IGPD/ft^2 and 81.9% at 3.2 IGPD/ft^2, respectively.

A time series analysis (Figure 3), depicting influent and effluent levels of Ammonia Nitrogen and Total Kjeldahl Nitrogen, indicated a consistently low amount of Ammonia Nitrogen and TKN in the effluent during the loading rates of 0.8 IGPD/ft^2 and 1.6 IGPD/ft^2. When the loading was increased to 3.2 IGPD/ft^2, results were more erratic but displayed a definite increase in the amount of Ammonia Nitrogen and TKN in the effluent.

TABLE 3

SUMMARY OF RBC PROCESS RESULTS

SUMMER OPERATION

	INFLUENT CONCENTRATIONS		% REDUCTIONS		EFFLUENT QUALITY			RATIOS	
Hydraulic IGPD/ft^2	NH_3-N mg/l	TKN mg/l	NH_3	TKN	Avg. NH_3 mg/l	Avg. TKN mg/l	Samples $>$1 mg/l NH_3-N	$\frac{NO_3}{NH_3}$	$\frac{Alk.}{NH_3}$
0.8	15.5	18.1	99.3	90.9	0.10	1.50	0%	89%	7.33
1.6	13.8	15.4	99.0	92.2	0.14	1.21	0%	85%	8.56
2.4	17.3	21.0	98.5	86.2	0.25	2.8	0%	82%	5.59
3.2	13.8	15.8	94.6	81.9	0.77	2.85	28.6%	76%	8.14

FIGURE 2

EFFECT OF HYDRAULIC LOADING ON NH_3-N and TKN REMOVAL

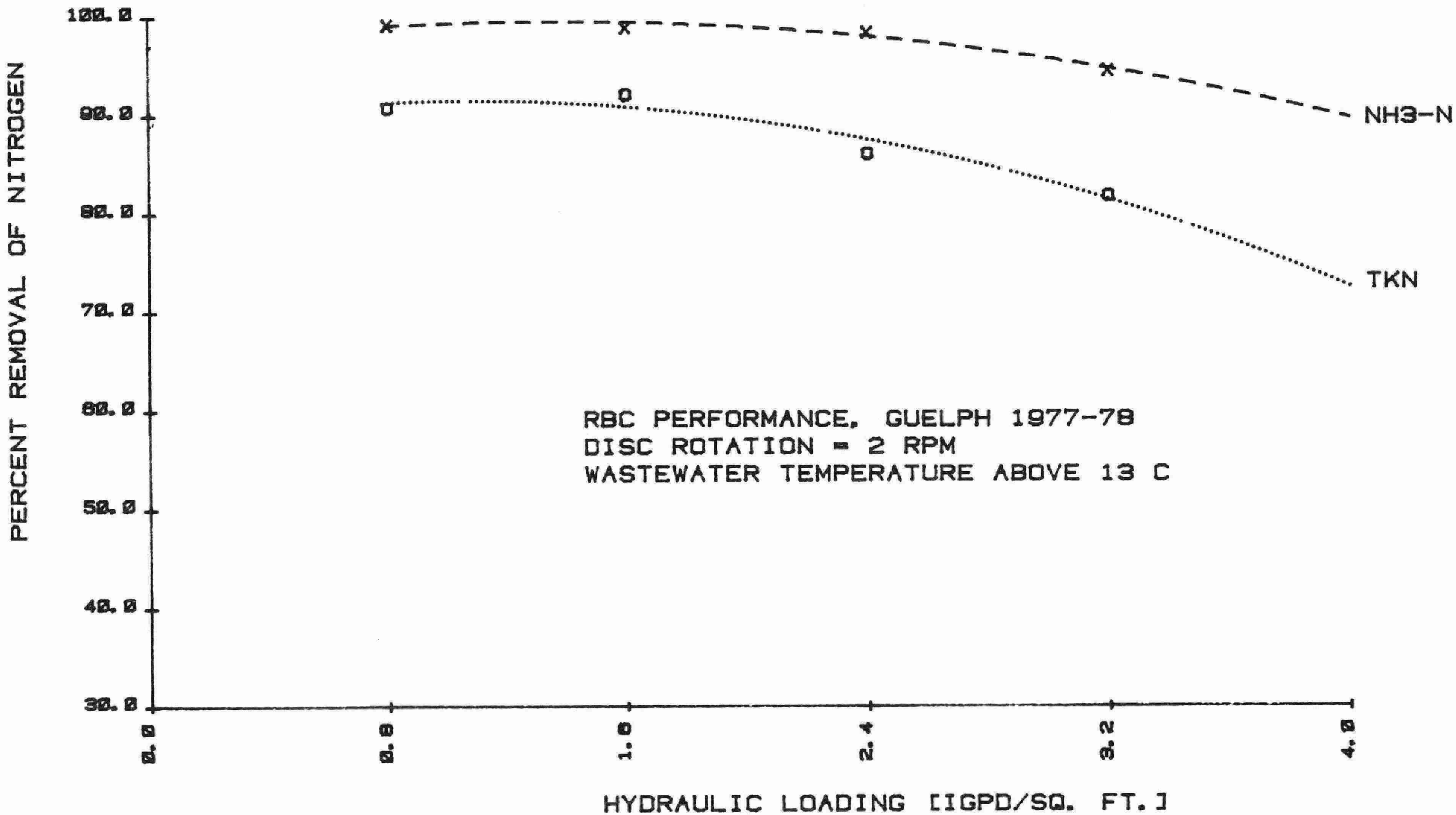
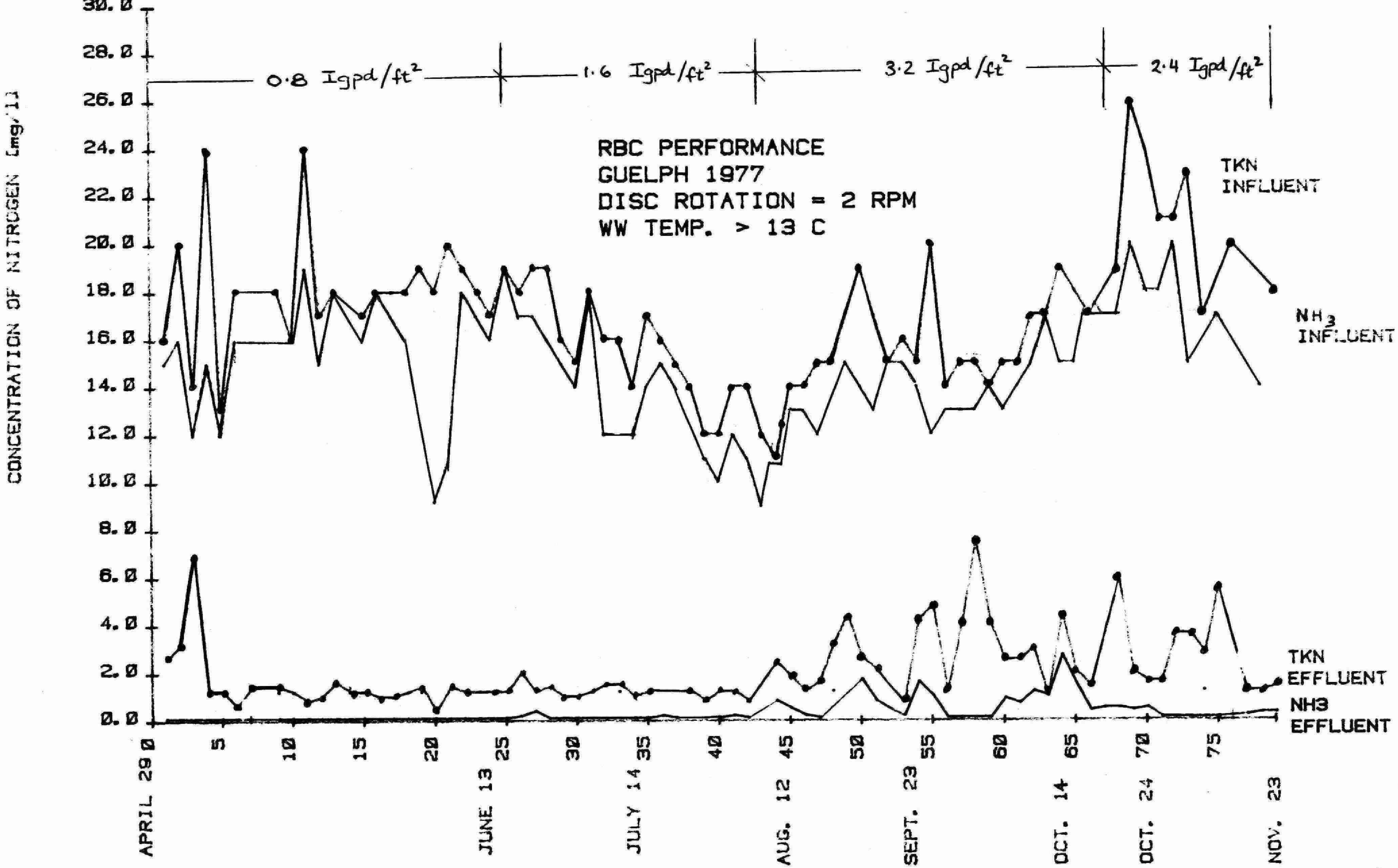


FIGURE 3

TIME SERIES ANALYSIS OF INFLUENT AND EFFLUENT NH_3-N AND TKN

DURING SUMMER OPERATION



When the loading was reduced to 2.4 $IGPD/ft^2$, the NH_3-N effluent concentration returned to a stable and consistently low level but the TKN values were more erratic than the NH_3-N.

An analysis of nitrification on a stage-by-stage basis (Figure 4) indicated that at the low hydraulic loading of 0.8 $IGPD/ft^2$, most of the Ammonia Nitrogen was oxidized in the first and second stages of the RBC unit. At the higher loading of 3.2 $IGPD/ft^2$, the removal of Ammonia Nitrogen was equally distributed between the five stages of the RBC unit. This would indicate that during nitrification at the higher loading of 3.2 $IGPD/ft^2$, there was a more efficient utilization of the surface area provided for biological growth.

According to theory (25), the complete conversion (100%) of Ammonia Nitrogen to Nitrate Nitrogen is unattainable because as much as 20% can be lost due to cell synthesis. Results obtained from this RBC testing did not indicate a fixed conversion ratio, but varied according to the hydraulic loading. Specifically, the production of Nitrate Nitrogen per unit of Ammonia Nitrogen removed decreased as the hydraulic loading increased (Figure 5; Table 3, Column 9). One explanation for variations in the conversion ratio is that low hydraulic loadings provided sufficient retention time for some Organic Nitrogen to be hydrolyzed to NH_3-N, thereby providing more NH_3-N, than was available for oxidation. Accordingly, conversion ratios of NH_3-N to NO_3-N in excess of 80% were obtained.

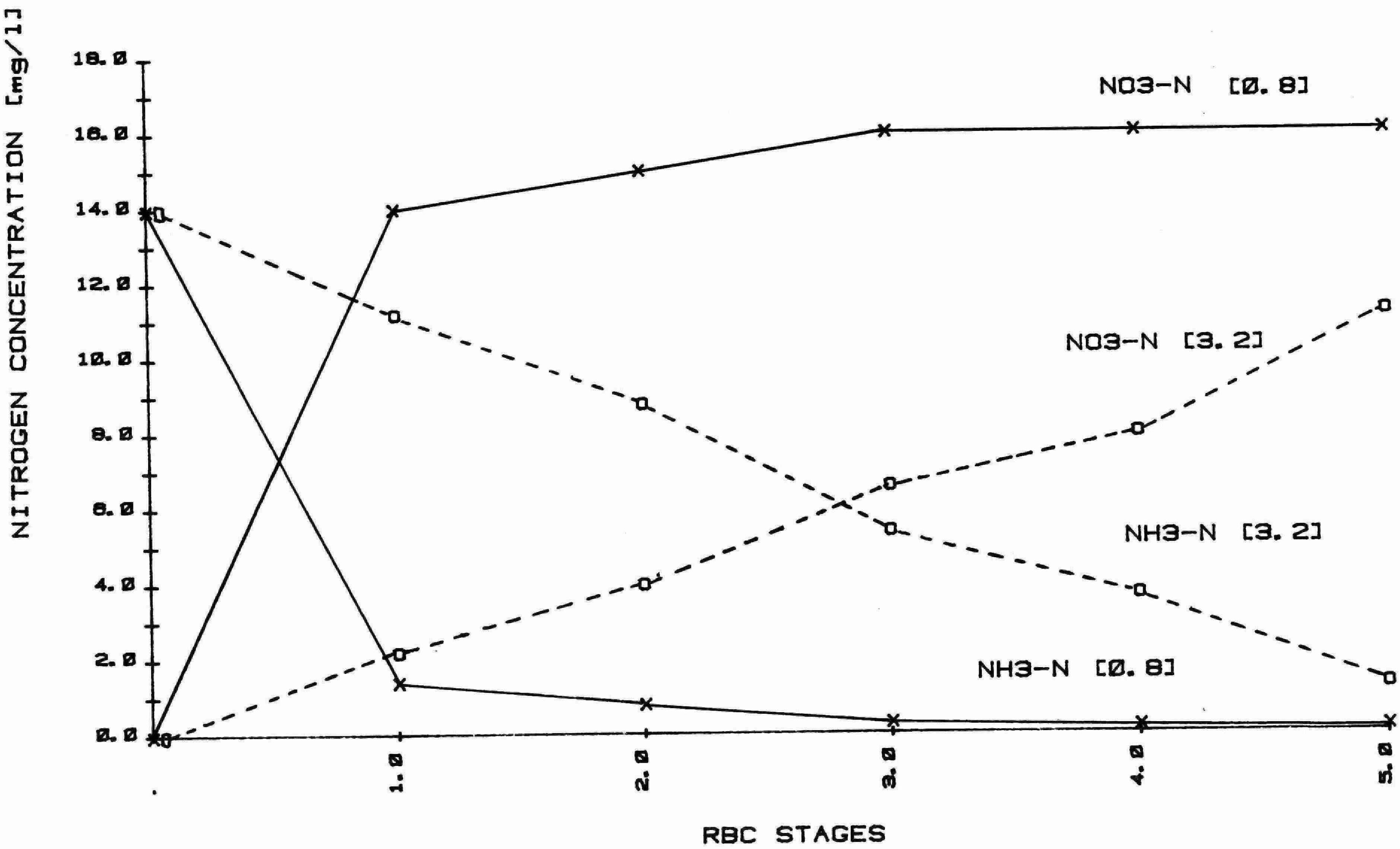


FIG. NO. 4 PROFILE OF NITROGEN COMPOUNDS IN THE RBC

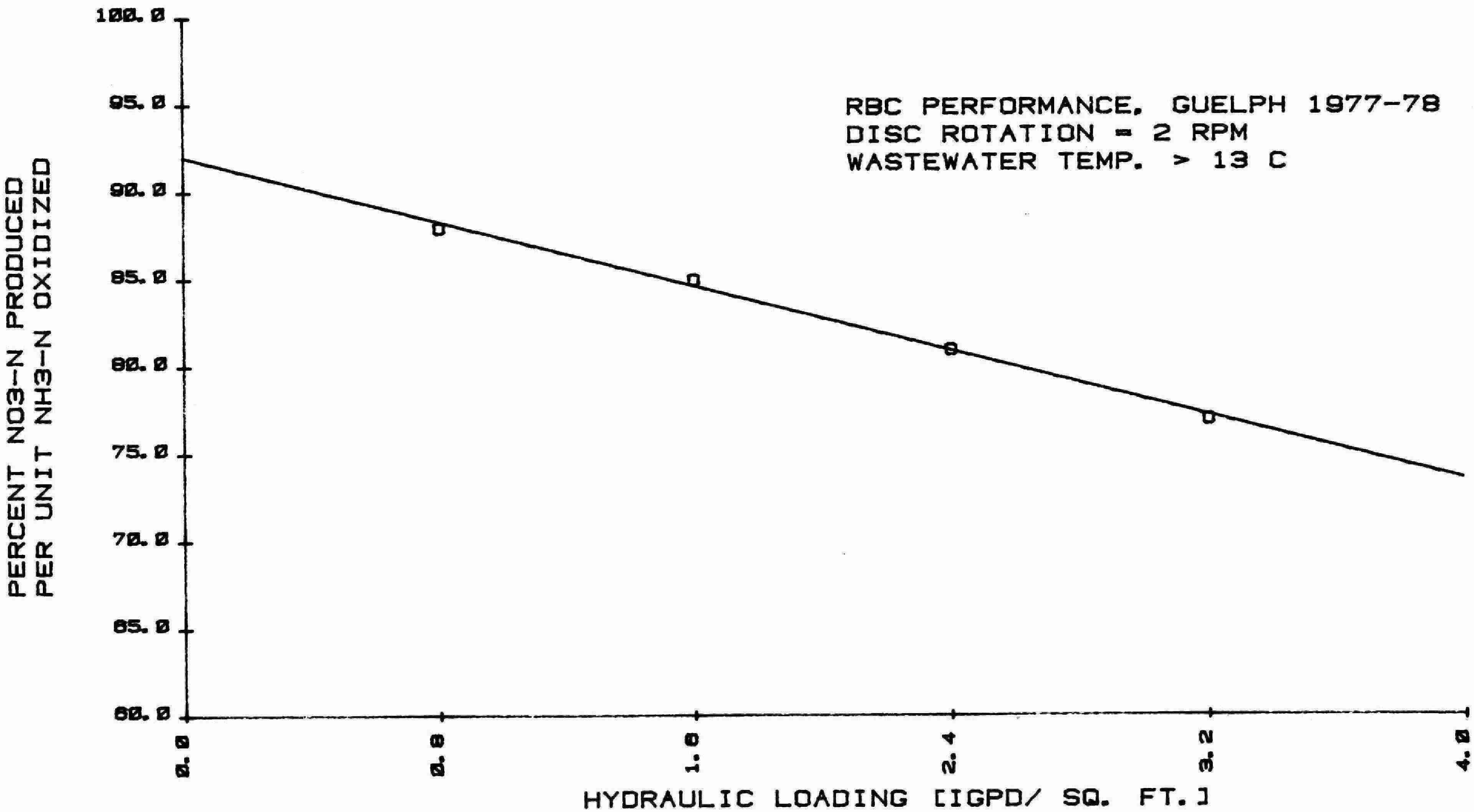


FIG. NO. 5 EFFECT OF HYDRAULIC LOADING ON NO3-N PRODUCED /NH3-N OXIDIZED

Further support for this argument was obtained by observing the removal of Organic Nitrogen during the RBC testing. Table 4 shows that the removal of Organic Nitrogen decreased with increasing hydraulic loading, thereby complementing the theory that at low hydraulic loadings Organic Nitrogen compounds could have been converted to Ammonia Nitrogen. The ratio of the amount of alkalinity required per unit of NH_3-N oxidized (Table 3, Column 10), when computed for all four summer hydraulic loadings, approximated the theoretical Alkalinity/NH_3-N ratio of 7:1 (2).

4.2 Effect of Disc Rotational Speed on Nitrification

The disc rotational speed of the RBC unit significantly affected the removal of Ammonia Nitrogen. Figure 6 indicates that under the same range of hydraulic loadings and wastewater temperatures, a higher degree of Ammonia Nitrogen removal was obtained at a disc speed of 2 rpm (15.7 ft/min), than was obtained at a disc speed of 1 rpm (7.85 ft/min). A similar observation was noted for TKN removal, i.e. significant improvement in the TKN removal could be attained by increasing disc rotational speed (Figure 7).

DO measurements substantiated earlier studies (21) by indicating that an appreciable amount of dissolved oxygen was added to the mixed liquor when disc speed was increased from 1 rpm to 2 rpm (Table 5). Although the thickness of the fixed-film of biological slime was not measured, it appeared from visual observations that the higher disc speed maintained thin and active layers of biomass on the surface of the discs.

TABLE 4

ORGANIC NITROGEN REMOVAL

Hydraulic Loading ($IGPD/ft^2$)	0.8	1.6	2.4	3.2
Parameter				
Organic Nitrogen Influent (mg/l)	2.67	1.69	3.67	2.18
Organic Nitrogen Effluent (mg/l)	1.43	1.10	2.54	1.97
% Removal	47%	34%	31%	10%

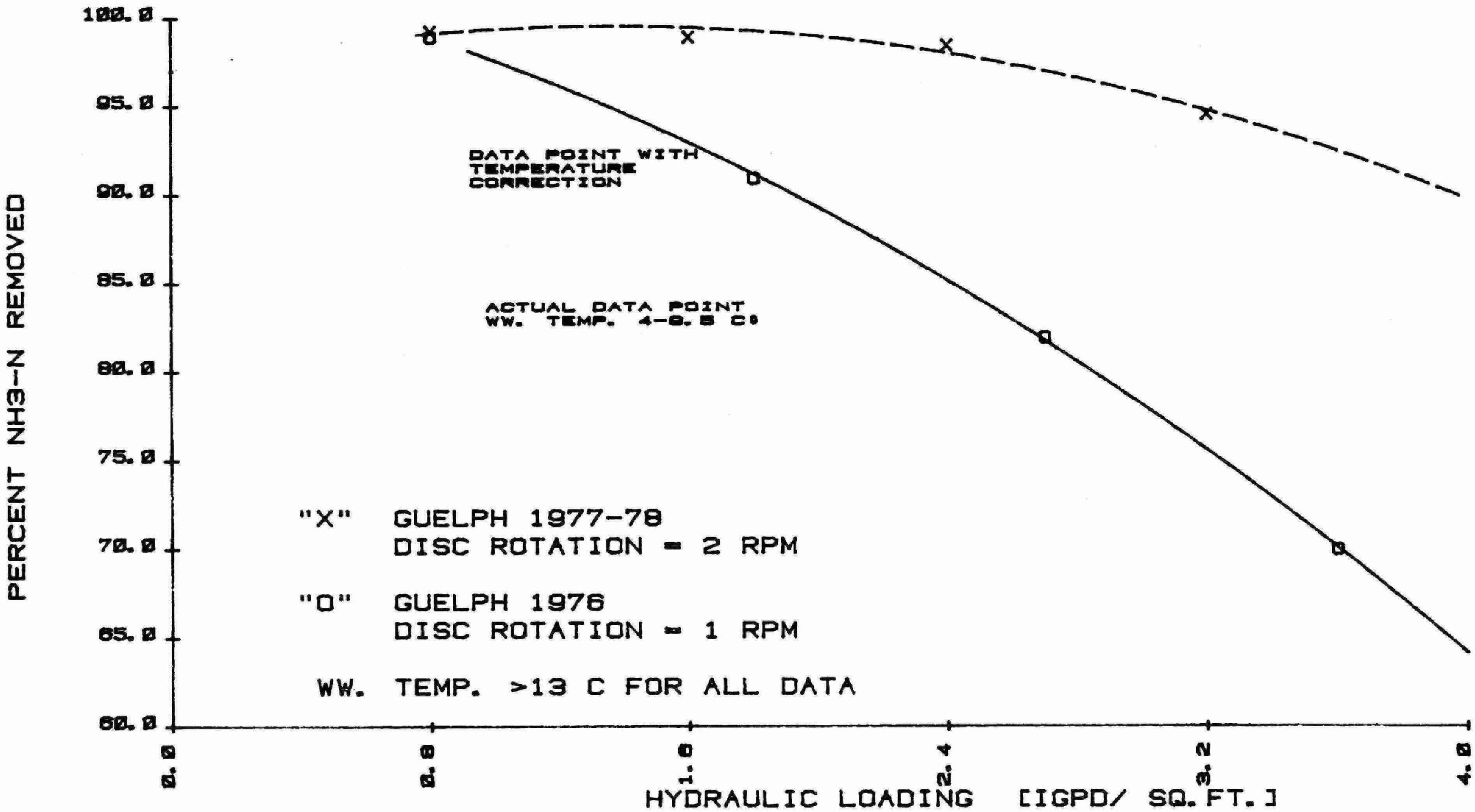


FIG. NO. 6 EFFECT OF DISC ROTATIONAL SPEED ON NH3-N REMOVAL

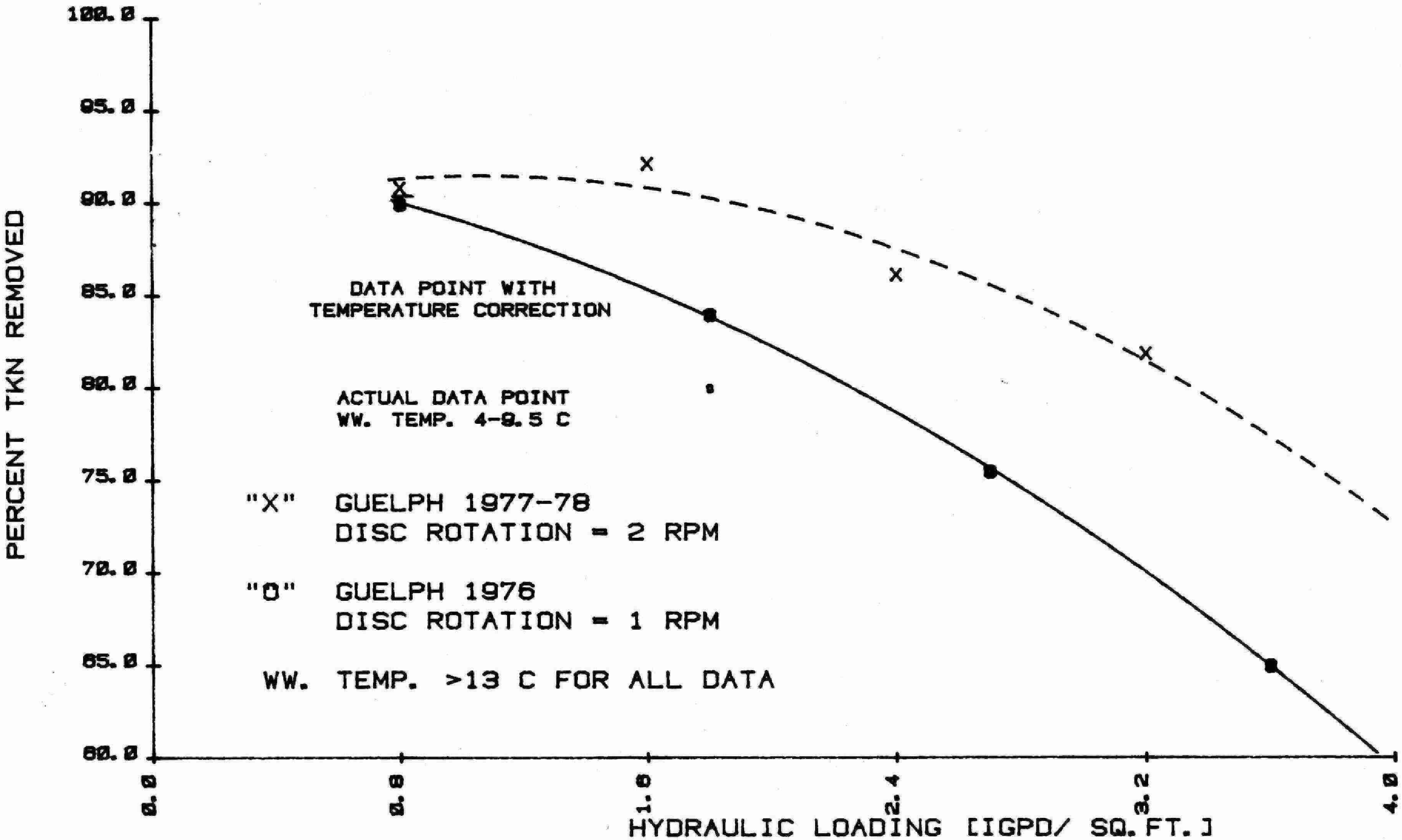


FIG. NO. 7 EFFECT OF DISC ROTATIONAL SPEED ON TKN REMOVAL

TABLE 5

EFFECT OF DISC ROTATIONAL SPEED

ON DISSOLVED OXYGEN CONCENTRATION

Disc Rotation (rpm)	Hydraulic Loading ($IGPD/ft^2$)	DO Range* (mg/L)	Wastewater Temperature (^{o}C)
1	0.8	0.4-3.5	19-21
1	2.7	0.3-1.7	19-21
2	0.8	3.0-5.2	20
2	1.6	2.4-4.4	20
2	3.2	2.4-3.2	19.5

* Range gives average DO concentration of first and fifth stage.

The RBC process exhibited first-order removal characteristics for the rate of Ammonia Nitrogen oxidation at rotational speeds of 1 rpm and 2 rpm (Figure 8). At the higher disc rotation speed (2 rpm), the rate of Ammonia Nitrogen removal continued as a first order mechanism up to 98.9%, with 98% Ammonia Nitrogen removed at a disc retention time* of 115 minutes. At the lower disc speed (1 rpm) the rate of NH_3-N removal continued as a first order mechanism up to 98%, with 98% NH_3-N removed after a retention time of 225 minutes. These results indicate that although disc rotational speed did not alter the order of the rate of Ammonia Nitrogen removed, a faster Ammonia Nitrogen removal rate was possible at a higher disc rotational speed. One data point in Figure 8, where a correction factor for temperature was employed, bears clarification. This data point, depicting the % Ammonia Nitrogen remaining at the hydraulic loading of 1.8 IGPD/ft^2 (disc retention time of approximately 145 minutes), was obtained during wastewater temperatures below 13°C (55°F). Since the other data points were representative of experiments conducted at wastewater temperatures above 13°C, a correction factor was utilized to compensate for the low wastewater temperatures (20).

Increases in power due to increases in disc rotational speed are of significance in the operation of the RBC process. Although results from power measurements conducted on the test RBC unit at Guelph can only apply to the motor and size of RBC unit tested, an increase in power for a higher disc speed was demonstrated. Results indicated that a 2% increase in power was required when disc speed was increased from 1 rpm to 2 rpm (for power measurement calculations see Appendix A).

* Disc Retention Time is defined as the time that wastewater is detained in the biological zone of the RBC unit.

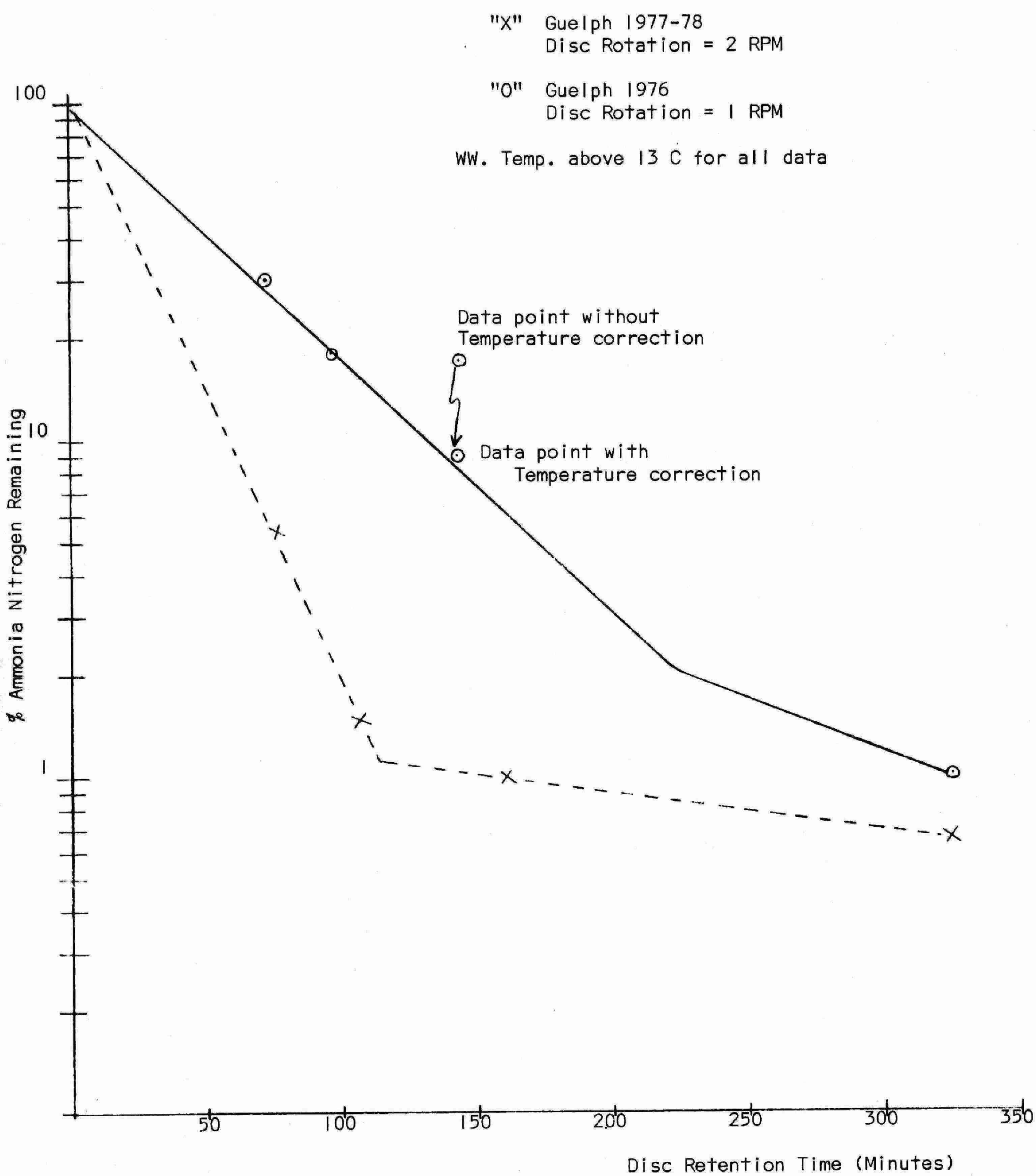


Fig. No. 8 Order of Ammonia Nitrogen Removal

5. PROCESS RESULTS AND DISCUSSION - WINTER OPERATION

"Winter Conditions" defined earlier for wastewater temperatures below 13^{o}C, prevailed between November 25, 1977 and January 23, 1978. During this period, the RBC unit was hydraulically loaded at a constant rate of 2.4 IGPD/ft^{2}. Since the above loading was also examined under "summer conditions", an ideal opportunity was attained to evaluate the effect of wastewater temperatures below 13^{o}C on the biological nitrification capability of the RBC process. It should be mentioned, however, that although the hydraulic loading of the RBC process was maintained constant (2.4 IGPD/ft^{2}) over the duration of the summer and winter testing periods, a significant difference in the mass loading of Ammonia Nitrogen and TKN to the RBC unit was observed, i.e. the Nitrogen mass loadings of summer were higher than those of winter. This difference in Nitrogen mass loading intensity could have affected Ammonia Nitrogen and TKN removals (Table 6).

5.1 Effect of Temperature on Nitrification

At the hydraulic loading of 2.4 IGPD/ft^{2}, the removal of Ammonia Nitrogen decreased as the wastewater temperature decreased. Specifically, the Ammonia Nitrogen removal level dropped from 98.5% (at the temperature range of 14^{o}C to 16^{o}C), to 88.6% (at the temperature range of 1^{o}C to 10^{o}C). Figures 9 and 10 show time series analyses of biological nitrification over the duration of the "winter" period. A smoothening of the time series curve (Figure 9) for the NH_3-N effluent indicates a progressively increasing

TABLE 6

SUMMARY OF RBC RESULTS

A SUMMER-WINTER OPERATIONAL COMPARISON

	INFLUENT CONCENTRATION			% REDUCTION		EFFLUENT QUALITY			ENVIRONMENTAL	
	Hydraulic IGPD/ft^2	NH_3-N (mg/l)	TKN (mg/l)	NH_3	TKN	Avg. NH_3 (mg/l)	Avg. TKN (mg/l)	% Effluent Samples >1 mg/l NH_3	Temp. Range °C	DO (mg/l)
SUMMER	2.4	17.3	21.0	98.5	86.2	0.25	2.80	0%	14-16	2.5-6.5
WINTER	2.4	11.9	14.6	88.6	82.7	1.05	2.68	47%	1-10	3.7-9.0

FIGURE 9

TIME SERIES ANALYSIS OF INFLUENT AND EFFLUENT NH_3-N
DURING WINTER OPERATION

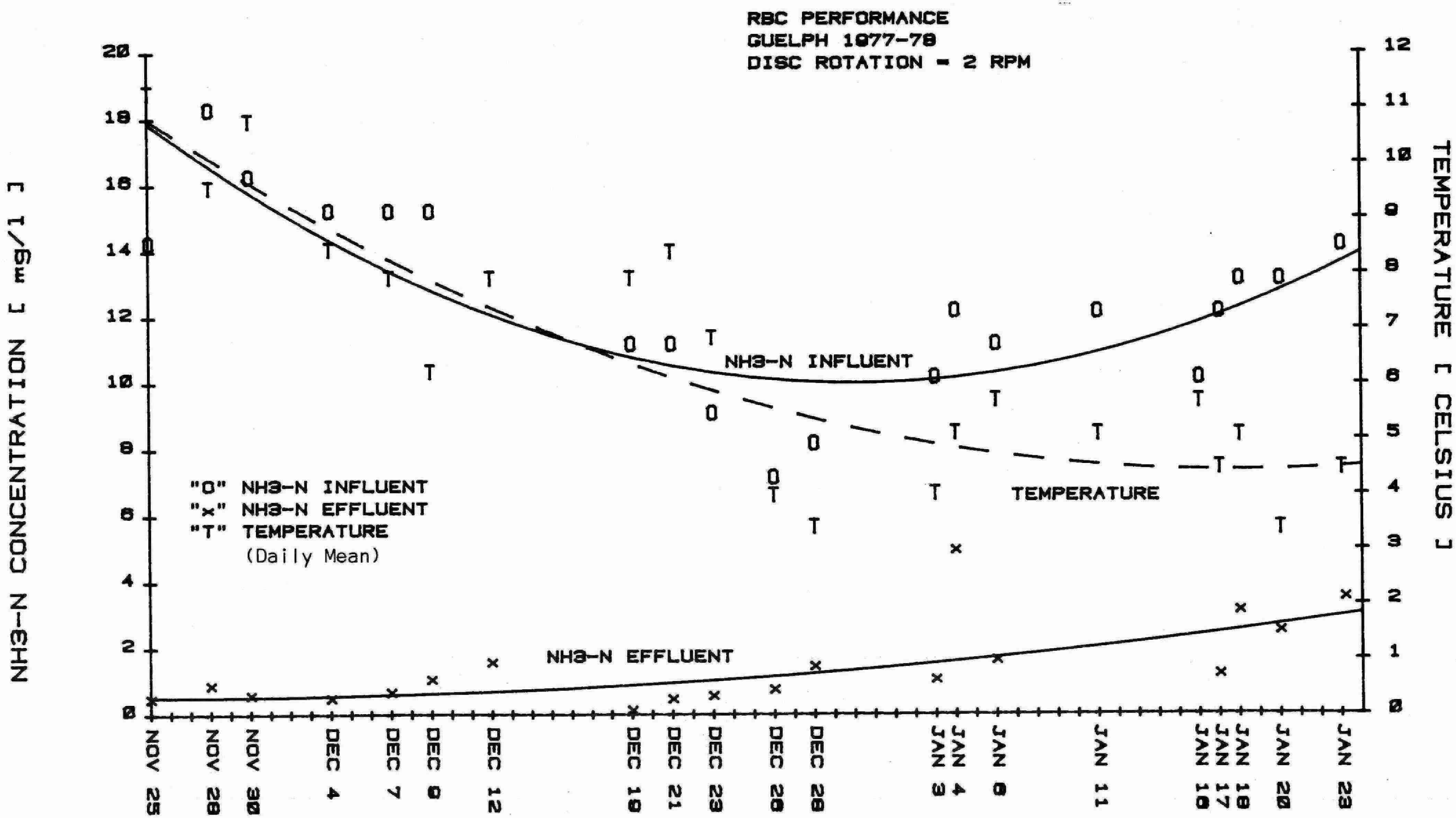
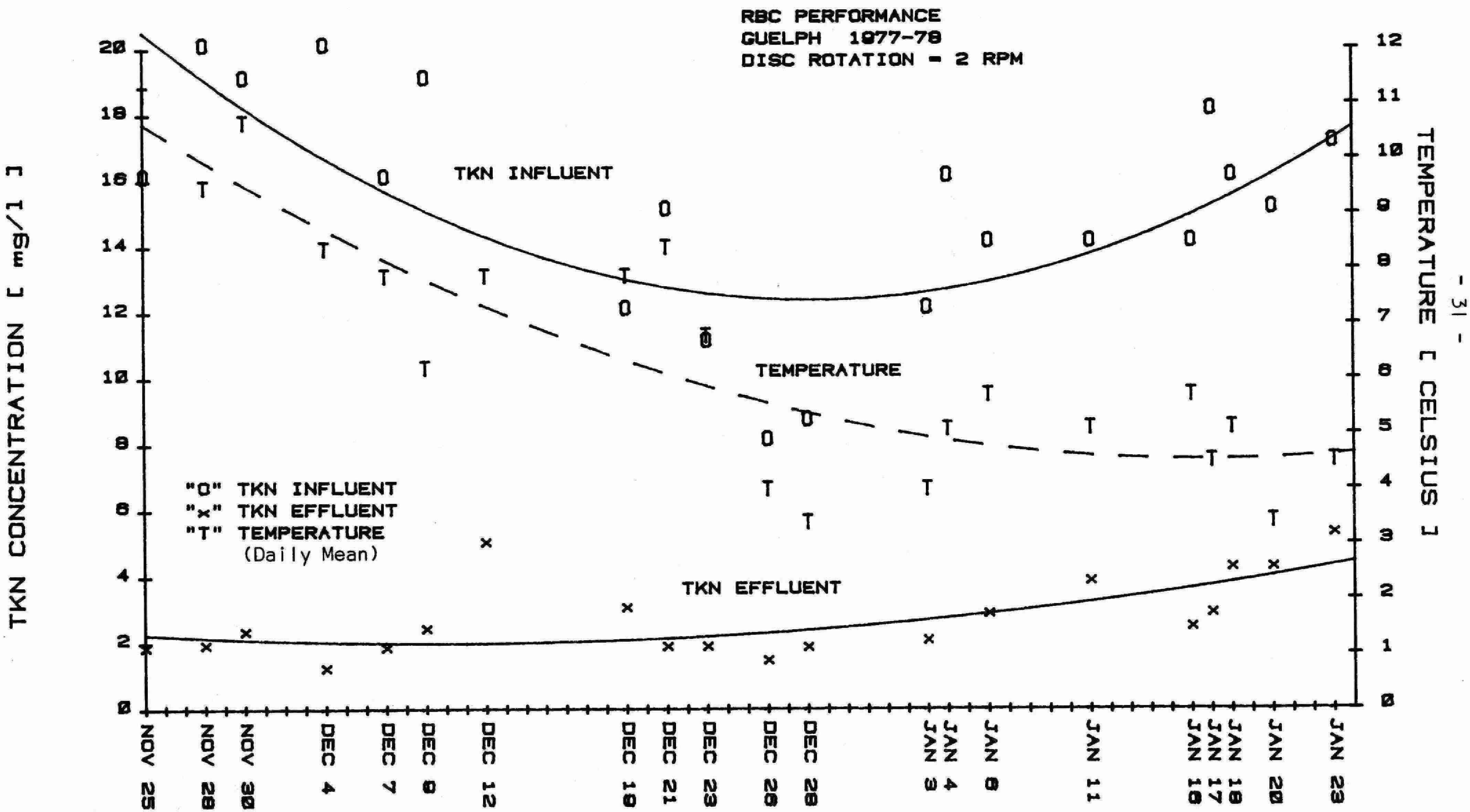


FIGURE 10

TIME SERIES ANALYSIS OF INFLUENT AND EFFLUENT TKN

DURING WINTER OPERATION



amount of NH_3-N in the effluent. It can also be ascertained from the time series analysis that nitrification gradually decreased as the mean wastewater temperature dropped from $11^{\circ}C$ to $4.5^{\circ}C$.

Figure 10 shows a time series analysis of TKN removal over the winter period. In particular, a gradual increase in effluent TKN concentration is demonstrated for daily mean wastewater temperatures below 7°-$8^{\circ}C$.

Weekly temperature and DO measurements of all five stages of the RBC unit were recorded throughout the winter testing period. This data provided a profile analysis of temperature and DO variations that could be expected within a RBC. Over the winter testing period, the average temperature of the wastewater was found to decrease from $7^{\circ}C$ at stage 1 to $3.5^{\circ}C$ by stage 5. Average dissolved oxygen measurements showed an increase from 4.7 mg/L at stage 1 to 6.9 mg/L at stage 5 (Table 7).

5.2 Effect of Process Upset on Nitrification

The rotation of the discs ceased twice due to accidental unplugging of the RBC unit during the winter. This arrestation of disc rotation was observed to have upset the nitrification process. No further deliberate attempts were made to upset the process as the accidental upsets seemed to have provided enough information so as to satisfy the "Objectives".

The first upset occurred on January 23, 1978, with the disc rotation interrupted for approximately 36 to 48 hours. The bacterial slime on the portions of the discs exposed to the atmosphere sustained significant dehydration. With the resumption of disc rotation, this dry, flaky, biomass sloughed off the surface of the discs, leaving areas void in bacterial

TABLE 7

AVERAGE TEMPERATURE AND DO PROFILES

ACROSS RBC STAGES DURING WINTER OPERATION

Location in RBC	*DO (mg/l)*	*Wastewater Temperature (°C)*
Stage 1	*4.7*	*7.0*
Stage 2	*5.2*	*6.0*
Stage 3	*5.7*	*5.2*
Stage 4	*6.5*	*4.4*
Stage 5	*6.9*	*3.5*

growth. Patches, void of biomass, were most noticeable in the fourth and fifth stages of the RBC unit, where the surfaces of the discs had normally been covered with very thin layers of biological growth. Stages 1, 2 and 3, where the slime layers were slightly thicker, showed no bare patches.

Following the first upset, an immediate loss in nitrification was observed (Figure 11), i.e. effluent NH_3-N concentration increased from under 4 mg/l (Point A) before the upset to 11 mg/l (Point B) after the upset. A substantial recovery in nitrification was observed during the week following the upset (Point C), with effluent NH_3-N levels decreasing to 5.4 mg/l by the end of the week. By this time, all bare patches on the disc surface had been replenished with new biological growth.

The second upset occurred on February 1, 1978, with the disc rotation interrupted for six hours. Patches, void of bacterial growth, did not appear on the disc surfaces from this second upset, and it was believed that six hours of arrested disc rotation was insufficient time for significant dehydration of the biomass.

A substantial loss in nitrification was observed, however, (Point D) and recovery of nitrification from this second upset was poor. In fact, after six weeks of recovery time, NH_3-N levels in excess of 8 mg/l were still being measured in the effluent.

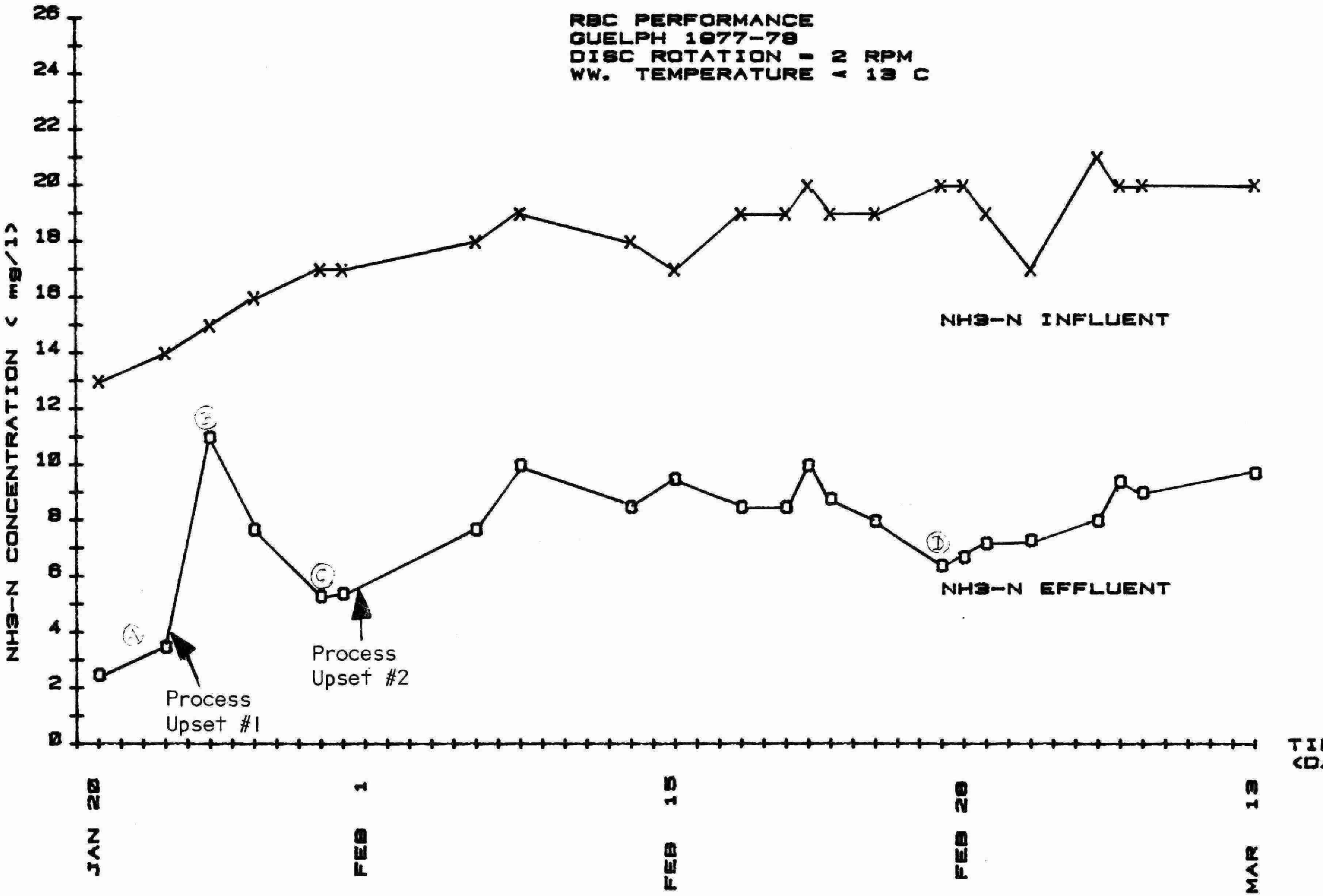


FIG. NO. 11 NITRIFICATION RECOVERY AFTER PROCESS UPSETS

It could not be ascertained from the data, whether the loss in nitrification was a direct result of either the first or second upset. However, it was believed that the loss in nitrification and the subsequent slow process recovery, could probably be attributed to the combined effects of both upsets as well as the low wastewater temperatures.

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APPENDIX A

RBC Power Measurement (Guelph, 1977-78)

The discs of the RBC unit at Guelph are driven by a Brooks Electric Gryphon AC motor, which is connected to a gear reducer and a further chain and sprocket speed reducer. The motor has the following specifications: 0.33 hp, 110/220 V, 60 Hz, 5.0/2.5 A, 1720 rpm.

At 1 rpm (disc-rotation), the following power measurements were taken:

Volts (V)	Amps (A)	Watts (W)
115	3.93	88-100 Avg. 94

$$\text{Power Factor} = \frac{W}{VA} = \frac{94}{115 \times 3.93} = 0.21$$

$$\text{Horsepower} = \frac{W \times \text{Efficiency}}{746} = \frac{94 \times 0.6}{746} \quad \text{(assuming 50\% load)}$$

$$= 0.0756$$

At 2 rpm (disc-rotation), the following power measurements were taken:

Volts (V)	Amps (A)	Watts (W)
116	3 .95	88-100 Avg. 96

$$\text{Power Factor} = \frac{W}{VA} = \frac{96}{116 \times 3.95} = 0.21$$

$$\text{Horsepower} = \frac{W \times \text{Efficiency}}{746} = \frac{96 \times 0.6}{746} \quad \text{(assuming 50\% load)}$$

$$= 0.0772$$

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